Simulation of Methane Flows in Noncoal Mines

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT			
ft	foot	h	hour
ft^3	cubic foot	min	minute
ft/min	foot per minute	ppb	part per billion

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By Andrew B. Cecala[1] and Edward D. Thimons[2]

ABSTRACT

The Bureau of Mines has successfully tested a method to simulate methane (CH_4) flows from face areas through the returns of noncoal mines. This technique involves releasing a small quantity of tracer gas at a working area and sampling for that gas downstream in the return airways. By measuring the dilution of the tracer gas, the dilution of any volume of CH_4 released at the face can be calculated. This information is useful in selecting locations for CH_4 monitors and in deciding the necessity for permissible equipment in the returns.

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INTRODUCTION

Methane gas (CH$_4$) hazards exist in a number of noncoal mines in the United States. Although the mechanism by which CH$_4$ is emitted into a noncoal mine may vary according to the type of mine, large emissions of CH$_4$ are usually associated with face blasting. Most of the Louisiana salt mines have experienced gas outbursts at face areas during blasting. It is estimated that some of these outbursts may involve as much as several million cubic feet of gas, some of which is CH$_4$. Oil shale mines may experience significant CH$_4$ releases during blasting. At the Horse Draw experimental oil shale mine in Colorado, Bureau of Mines studies showed an average of 40 ft^3 of CH$_4$ being released per ton of rock broken during blasting.[3] For oil shale mines having similar CH$_4$ levels, blasting that fractures 1,000 tons of rock per shot can be expected to release 40.000 ft^3 of CH$_4$.

Large instantaneous CH$_4$ emissions present a safety hazard at face areas, but little is known about how the released CH$_4$ mixes with air at the face and how fast the CH$_4$ concentration dilutes to safe levels as the gas cloud travels from the face area through the return airways of the mine. Such information would be of value in selecting locations for CH$_4$ monitors in return airways and in deciding the necessity for permissible equipment at given locations in a return. This study does not simulate an outburst-type release, and its results could only be applied after the outburst pressure has equalized with that of the mine environment.

The Bureau of Mines has found that the tracer gas sulfur hexafluoride (SF$_6$) can be used to simulate the behavior of a CH$_4$ cloud. Sulfur hexafluoride is a colorless, odorless, inert gas that has been used for a number of years for various research studies.[4] It is available in gas cylinders containing approximately 1.5 ft^3 of gas. The cylinders are weighed before and after use to determine the exact volume released.

VERIFICATION TESTING

The Bureau procedure assumes that a small volume of tracer gas can represent a larger volume of CH$_4$ flowing through the returns. Also, it is assumed that gas clouds of equal size will have identical dilution, independent of their concentration, if they flow from identical locations. The Bureau procedure uses a small volume of gas to represent a larger volume of gas; for example, 1 ft^3 of tracer gas to simulate a million ft^3 of CH$_4$. This can be done by either releasing a 1-ft^3 plug of SF$_6$ or by releasing that 1 ft^3 into 1 million ft^3 of air. In the first case, the 1-ft^3 plug of tracer gas will have diluted into 1 million ft^3 of air at some point as it flows downstream. In either case, the SF$_6$ concentration (1×10^{-6}), for 1 million ft^3 CH$_4$ release volume is assumed to be equivalent to pure CH$_4$. We can then predict the peak CH$_4$ concentrations that will occur at given locations in the return by measuring the peak SF$_6$ concentrations at those locations. If a peak SF$_6$ concentration of 10^{-7} occurs, there is a peak concentration dilution factor of 10 for that location, and the estimated peak CH$_4$

[3]Sapko, M. J., J. K. Richmond, and J. P. McDonnell. Continuous Monitoring of Methane in a Deep Oil Shale Mine. Pres. at 15th Oil Shale Symposium (CO School of Mines, Golden, CO, Apr. 28-30, 1982), 1983, pp. 62-73; available upon request from J. H. Gary, CO School of Mines, Energy Technol. Center, Golden, CO.

[4]Turk, A., S. M. Edmonds, H. L. Mark, and G. G. Collins. Sulfur Hexafluoride as a Gas-Tracer. Environ. Sci. Technol., v. 2, No. 1, 1968, pp. 44-48.

Timko, R. J., and E. D. Thimons. Sulfur Hexafluoride as a Mine Ventilation Research Tool-Recent Field Applications. BuMines RI 8735, 1982, 15 pp.

concentration will be 10%. This relationship is true if 1 ft^3 of SF_6 is released into 1 million ft^3 of air, which we will call case 1. However, if 1 ft^3 of SF_6 is released as a plug (into 1 ft^3 of air), case 2, then the measured peak concentration dilution factor would be less than or equal to 10. Figure 1 illustrates areas 1 and 2.

In case 1, the SF_6 is uniformly mixed in 1 million ft^3 of air at the release point. The average concentration is 1 $\times$ 10^{-6}, and the peak concentration is also 1 $\times$ 10^{-6}. The gas dilutes as it flows downstream to the sampling location, distance X. In case 2, the 1-ft^3 plug of SF_6 is released and flows distance Y downstream before it dilutes into 1 million ft^3 of air, at which time it also has an average concentration of 1 $\times$ 10^{-6}. However, the peak concentration is higher than 1 $\times$ 10^{-6} because the gas concentration is in somewhat of a bell-shaped curve. The distance it then has to travel from the release point to the sampling location (X minus Y), is shorter than for case 1 (where the distance is X). Because of these two factors (higher peak and shorter travel distance), the measured peak concentration dilution factor for case 2 will always be less than or equal to the peak concentration dilution factor for case 1. Therefore, a plug release of SF_6 should always simulate the lowest peak concentration dilution factor
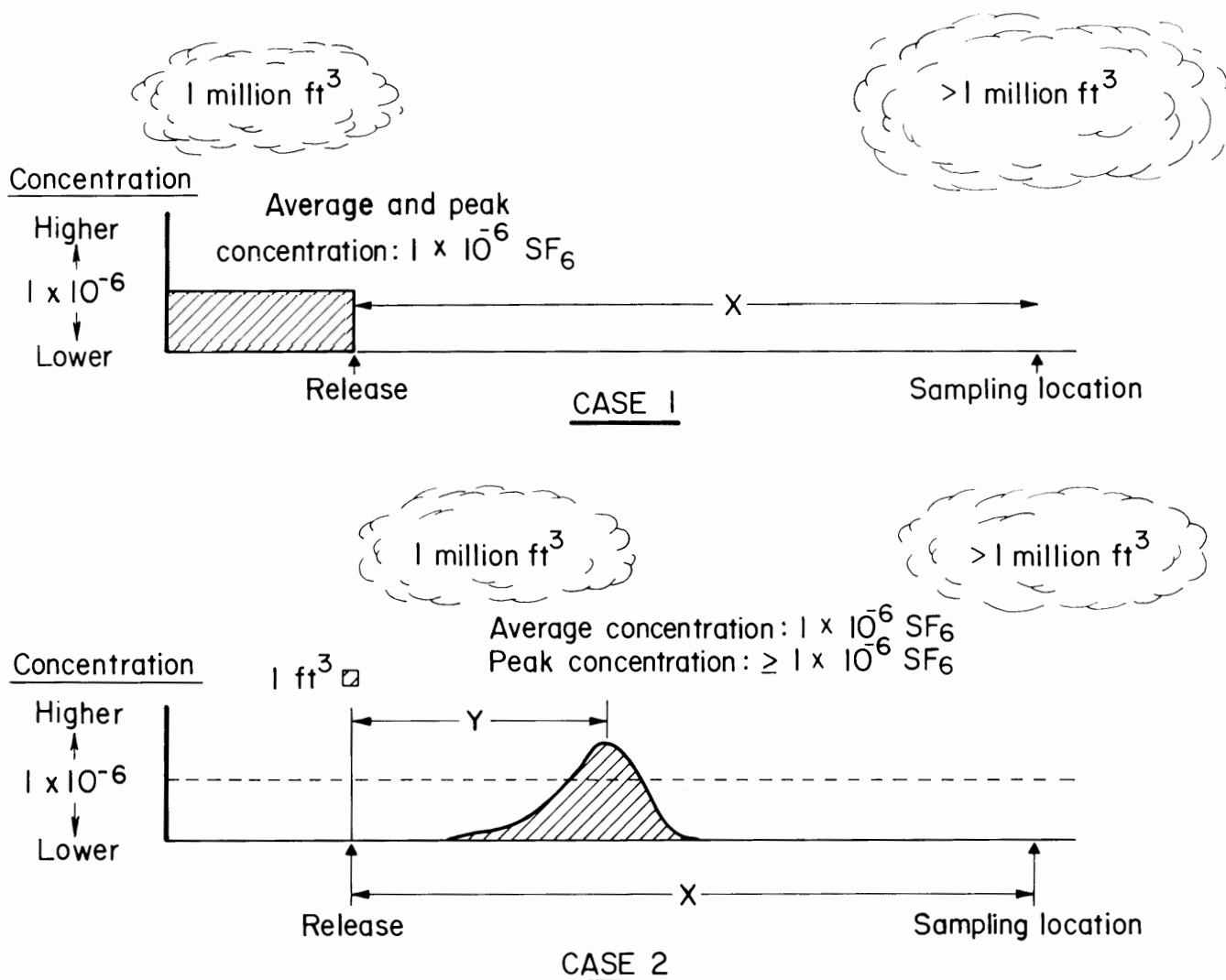

FIGURE 1. - Difference between large volume release and plug release.

and thus a worst-case situation. In order to assume a safety factor and study the worst-case situation, the Bureau of Mines uses the plug-release method in its studies.

To verify that SF_6 plug release provided a worst case, three tests were run at the Bureau's Lake Lynn Laboratory. In these tests, 0.024 ft^3 of SF_6 was released into different air volumes (1.0 ft^3, 14,000 ft^3, and 56,000 ft^3), and the air was sampled 325 ft and 1,500 ft downstream from the release point (fig. 2). A gas chromatograph was used to determine the peak SF_6 concentrations at the sampling locations (table 1).

Each test was repeated three times; the peak concentrations are the averages of these three tests. The results show that the peak concentrations that occur downstream of the release point decrease as the same amount of SF_6 is released into larger volumes. Therefore, if we use SF_6 to simulate a 56,000-ft^3 cloud of pure

TABLE 1. - Verification test results using 0.024 ft^3
of tracer gas

Volume of air into which tracer gas was released, ft^3	Peak gas concentration at sampling location,		Peak concentration dilution factor for 56,000 ft^3 of CH_4	
	Location A	Location B	Location A	Location B
1.0..........	1.42×10^{-6}	1.71×10^{-7}	0.3	2.5
14,000.......	5.17×10^{-7}	1.38×10^{-7}	.8	3.1
56,000.......	2.23×10^{-7}	6.6×10^{-8}	1.92	6.5

LEGEND

← Airflow

▓ Release area
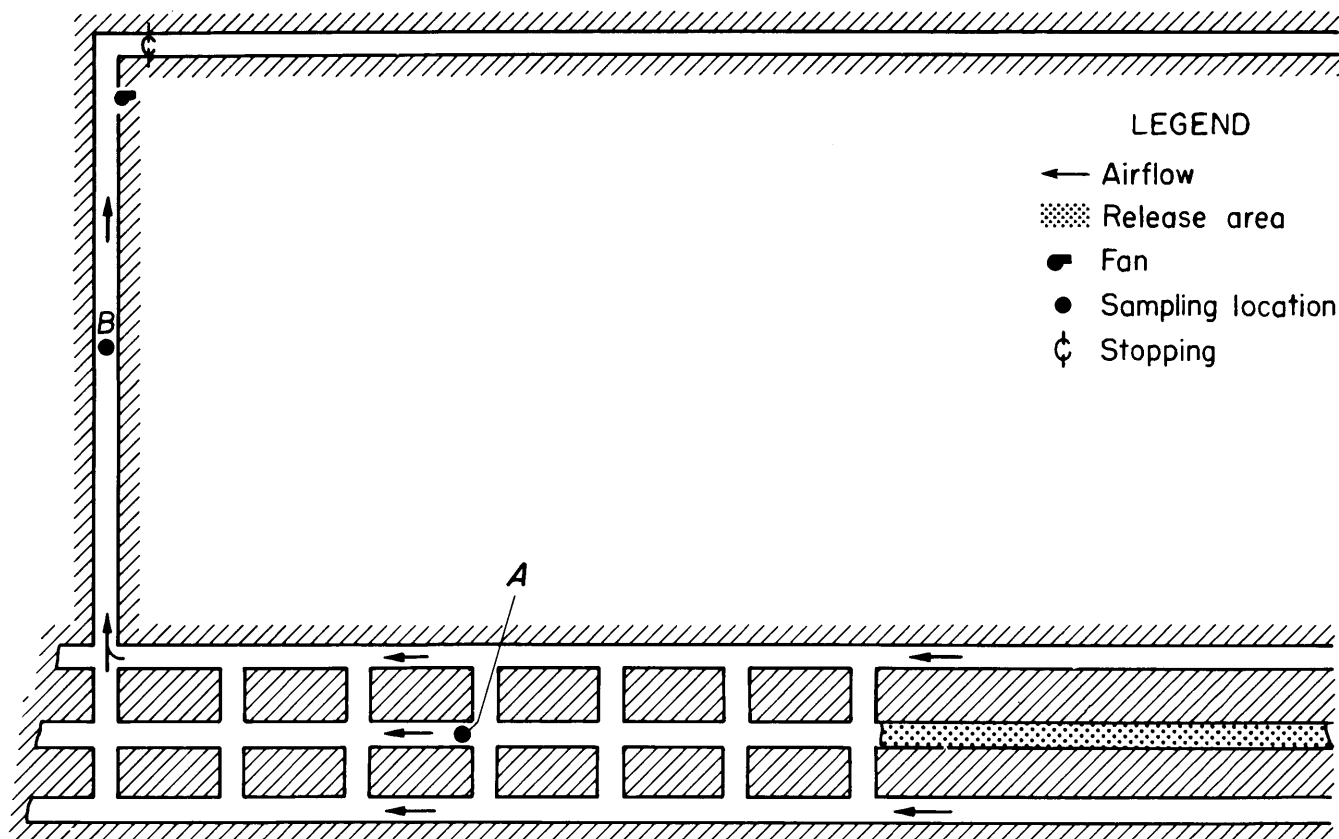
☞ Fan

● Sampling location

₵ Stopping

FIGURE 2. - Partial mine map showing verification testing at Lake Lynn Laboratory.

CH$_4$ flowing from a face area through the returns, the lowest (or worst-case) peak concentration dilution factor will be obtained by releasing the SF$_6$ as a point source or plug. In all three cases, it is assumed that an SF$_6$ concentration of

$$\frac{0.024 \text{ ft}^3}{56,000 \text{ ft}^3} = 4.29 \times 10^{-7}$$

is equivalent to 100% CH$_4$. The dilution factor is then obtained by dividing 4.29 × 10^{-7} by the peak SF$_6$ concentration, which occurs at the sampling location.

The closer the sampling location is to the release point, the greater the difference between a point source and a large-volume release. Figure 3 shows the flow of gas past both sampling locations, which represents an average of three separate runs. The difference between a release of SF$_6$ into 1.0, 14,000, and 56,000 ft^3 is greater at location A than it is at location B. This confirms that the point source release is always the worst case; however, further downstream, the difference between a point source and a large volume release becomes less.
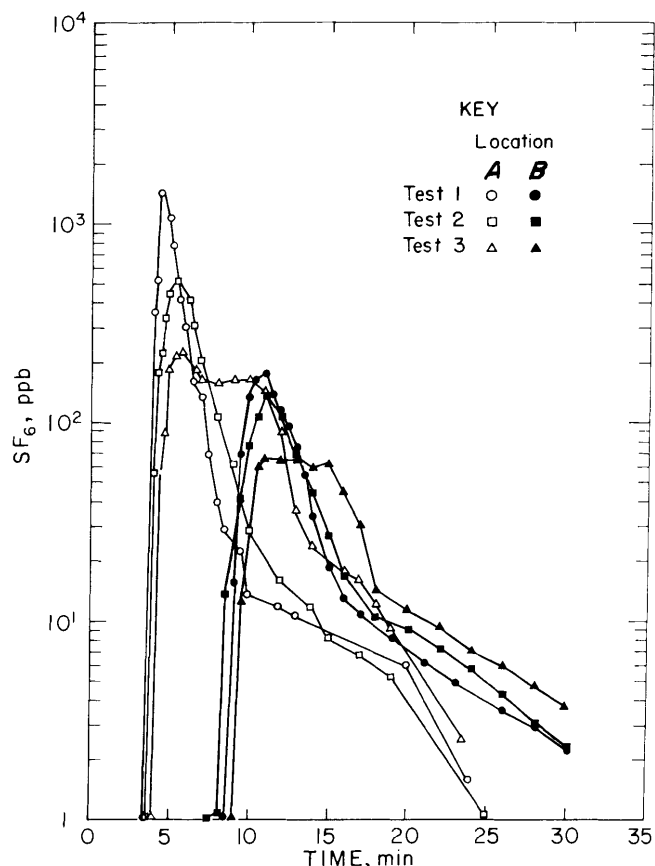

FIGURE 3. - Tracer gas concentration curves for verification testing.

MINE TESTING

Numerous tests were run at two large-opening mines using SF$_6$ to simulate CH$_4$ flows, two of which will be presented in this report. In all cases, SF$_6$ was released at a working face or bench and monitored at several locations along the return. The purpose of these tests was to determine at each sample location (1) the reduction in the peak gas concentration, and (2) the shape and slope of the gas concentration curve from initial detection to peak concentration.

In test 1, 2.27 ft^3 of SF$_6$ was released directly from a gas cylinder (fig. 4) at release point R (fig. 5). Samples were taken at three locations in the return airway, for approximately 2 1/2 h after release. The results of the test are shown in table 2.

Concentration is plotted as a function of time in figure 6. The average velocity from the release point to sampling location 2 was greater than location 1

TABLE 2. - Results from test 1

Location	Peak gas concentration	Time to reach peak conc, min	Distance from release point, ft	Calculated velocity, ft/min
1.......	1.02 × 10^{-6}	3	310	103
2.......	5.71 × 10^{-7}	6	750	125
3.......	1.49 × 10^{-7}	15	1,100	73

FIGURE 4. - Tracer gas being released from gas cylinder.

LEGEND

- ● Sampling location
- R Release location
- ← Airflow
- ₵ Stopping
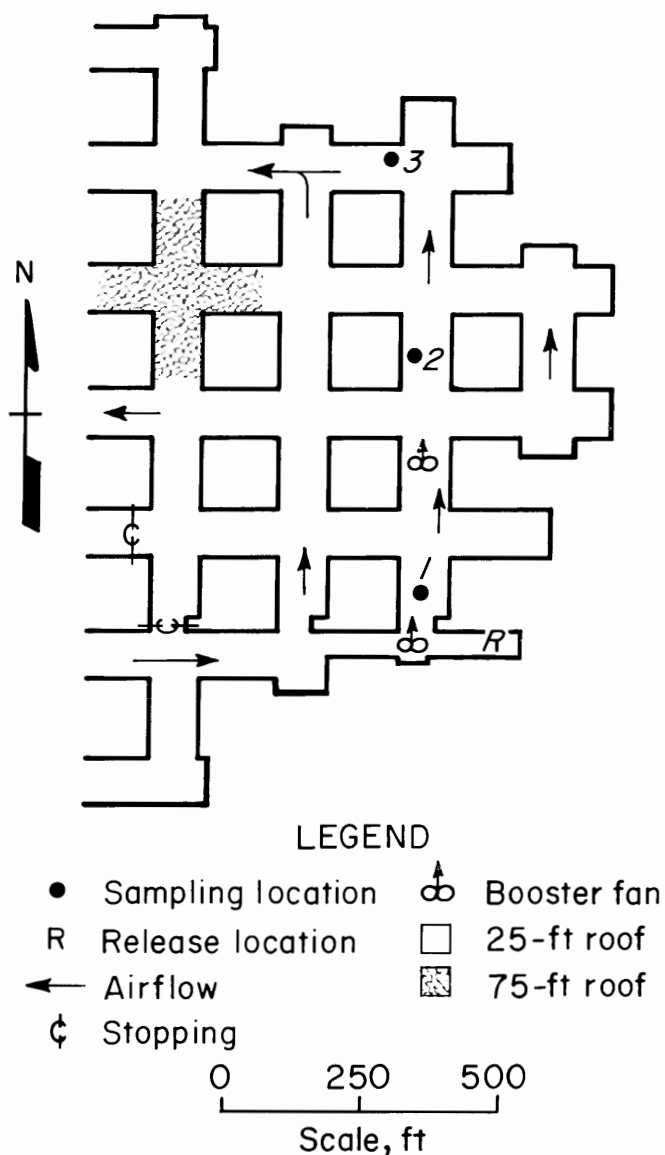- ⌀ Booster fan
- ☐ 25-ft roof
- ▨ 75-ft roof

FIGURE 5. - Partial mine map showing test 1.

because the two booster fans (fig. 5) increased the velocity once the gas flowed out of the dead heading.

If the mine operator wants to know the peak concentration of CH_4 that will occur at sample location 1 if 50,000 ft^3 of pure CH_4 is released during a blast, the values from table 2 can be used in the following relationships:

$$\frac{SF_6 \text{ peak concentration at sampling locations}}{SF_6 \text{ released (ft}^3)} = \frac{Z \text{ (peak } CH_4 \text{ concentration at sampling location)}}{CH_4 \text{ released (ft}^3)};$$

$$\frac{1.02 \times 10^{-6}, SF_6 \text{ concentration}}{2.27 \text{ ft}^3 \, SF_6} = \frac{Z, CH_4 \text{ concentration}}{50,000 \text{ ft}^3 \, CH_4}$$
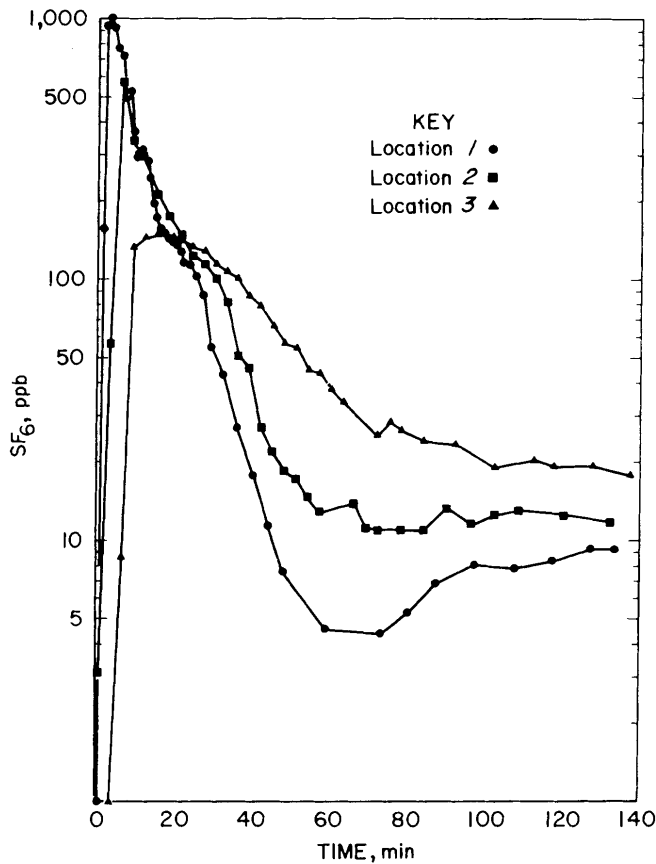
$$\therefore \quad Z = 0.022 = 2.2\% \, CH_4. \tag{1}$$

FIGURE 6. - Tracer gas concentration curves for test 1.

FIGURE 7. - Partial mine map showing test 2.

Therefore, a release of 50,000 ft^3 of CH_4 would result in a worst-case maximum CH_4 concentration at sampling location 1 of 2.2%. At sampling locations 2 and 3, the peak CH_4 concentrations would be 1.2% and 0.3%, respectively, for the worst-case estimate.

For test 2, the tracer gas was released in conjunction with a bench blast. Instead of releasing the SF_6 directly from a gas cylinder, it was placed in an airtight sampling bag, which was placed over a borehole filled with explosives
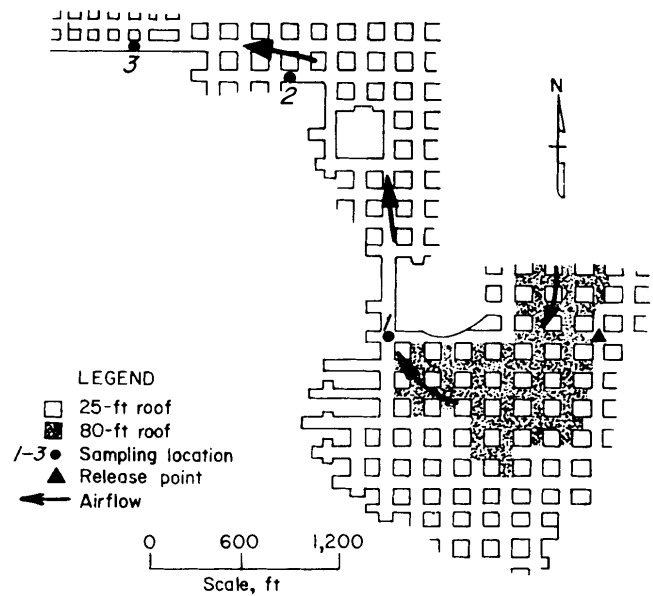
(release point in figure 7). When the shot was fired, the bag ruptured, releasing the tracer gas into the entry. Sampling was performed at three locations in the return airway. The total sampling time was much longer in this test because the ventilating airflow was lower. The results are shown in table 3. The change in gas concentration as a function of time is shown in figure 8.

No one was permitted in the mine during blasting. Although the first sample was not taken until 30 min after the blast, the peak concentrations were still captured for locations 2 and 3, and it is believed that the peak value or very close to the peak value was also captured for location 1. By using these peak concentration values in equation 1 to calculate gas reductions, it can be seen that substantial reductions in CH_4 concentrations would occur.

TABLE 3. - Results from test 2

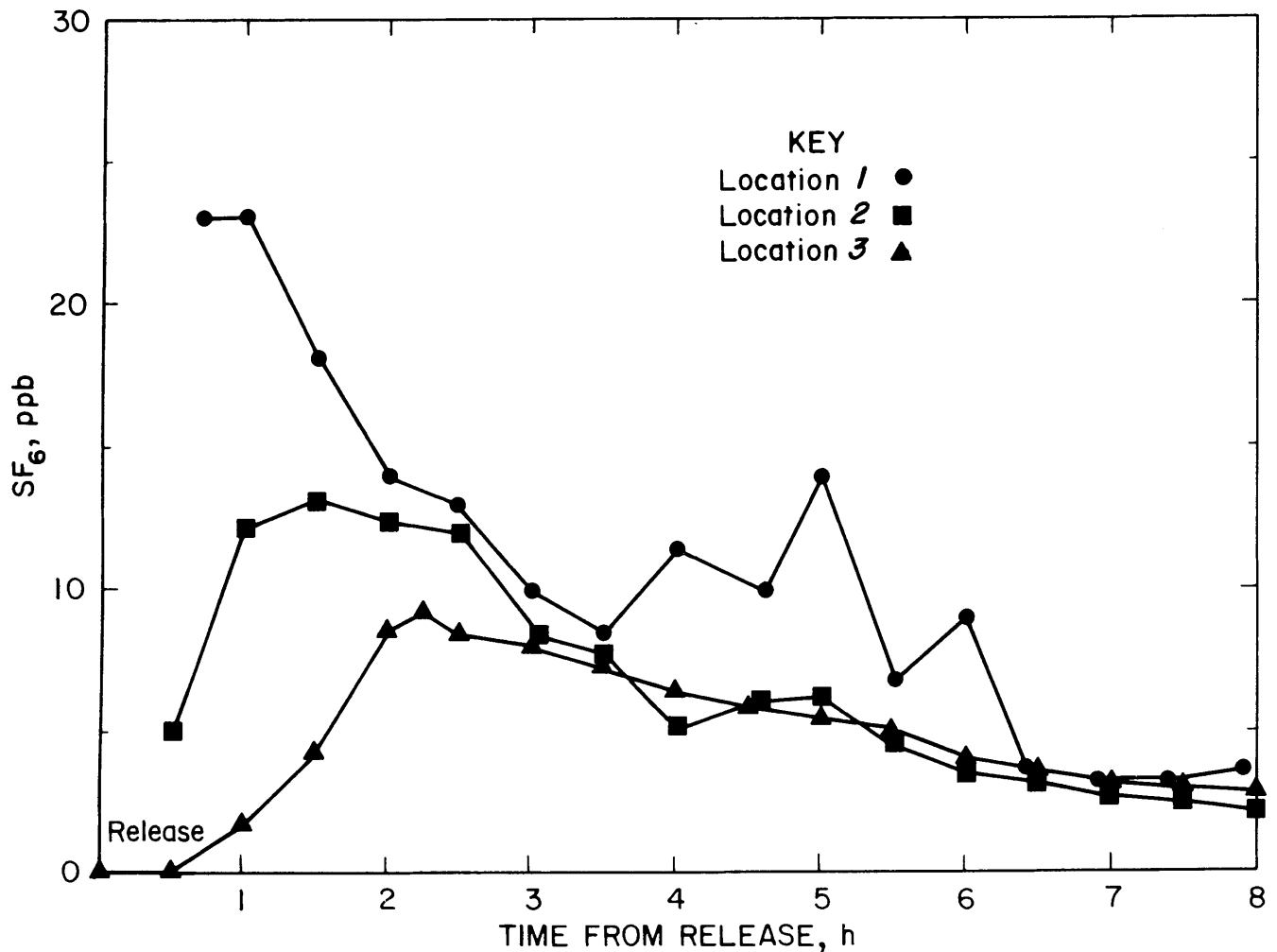| Location	Peak gas concentration	Time to reach peak conc, min	Distance from release point, ft	Calculated velocity, ft/min
1.......	2.3×10^{-8}	39	1,050	27
2.......	1.4×10^{-8}	95	2,925	31
3.......	$.9 \times 10^{-8}$	137	3,900	28

FIGURE 8. - Tracer gas concentration curves for test 2.

The reduction in CH_4 concentration as the gas flows from a release point to a sampling location in the return will vary for every release point and sampling location because the airflow pattern between any two mine points is never the same. Figure 9 shows that for test 2, gas flowing from the release point to the first return sampling location undergoes normal diffusion as it flows through multiple airways, and is diluted by fresh air at the dilution points (crosscuts) labeled 1, 2, and 3. These dilution points are a major cause of the substantial reduction in the gas concentrations as the gas flows to the first sampling location.
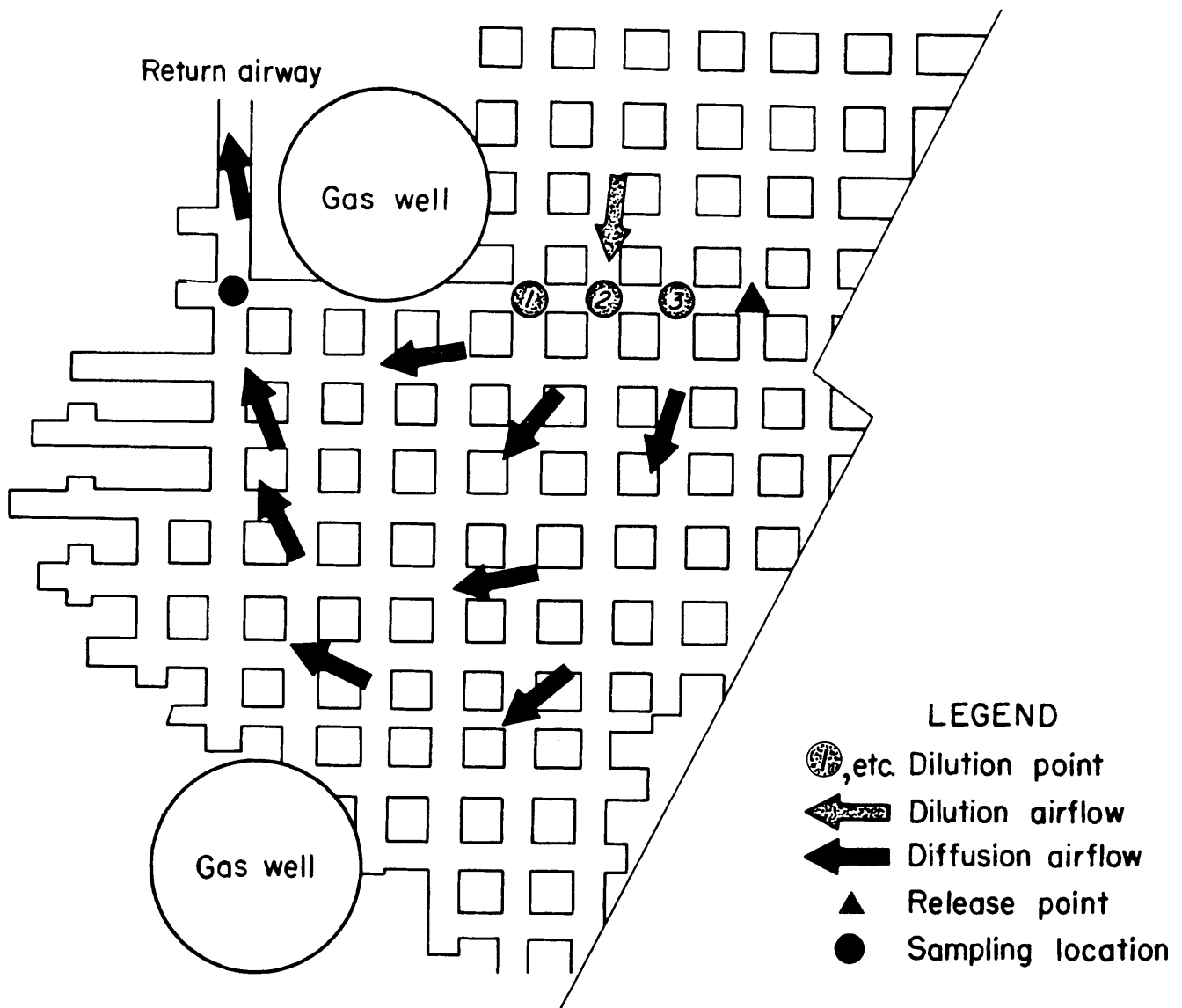
FIGURE 9. - Partial mine map showing dilution and diffusion.

CONCLUSIONS

SF$_6$ tracer gas can be used to simulate large-volume flows of CH$_4$ from face areas through return airways. The study did not simulate an outburst-type release, and the results would be applicable only after the outburst pressure has equalized with that of the mine environment. The information obtained can give guidelines for selecting CH$_4$ monitor locations and in deciding where permissible equipment is needed. However, because airflow patterns are different for every mine situation, test results from one location should be applied only to that location.